Strengthening Reinforced Concrete Beams Using Hybrid FRP Laminates

N. ATTARI[1], S. AMZIANE[1], and M. CHEMROUK[2]

[1]*LG2M, Université de Bretagne Sud, Lorient, France*

[2]*Université des Sciences et de la Technologie Houari Boumediene, Bab-Ezzouar, Algérie*

ABSTRACT: The use of composite materials for the strengthening and repair of structural elements is being increasingly used throughout the world. However, in addition to its higher cost, the greater strength of the FRP is inducing fragile behaviour at or close to failure. This fragile behaviour is not recommended for structures in seismic regions.

In this sense, the aims of the present study, is to evaluate the contribution of the external reinforcement of concrete beams, reinforced by hybrid FRP laminates; which consist of the combination of one-way glass and carbon fibres as well as a bidirectional hybrid fabric glass carbon, on their performance in term of ductility, strength and mode of failure.

An experimental program on a total of ten concrete beams reinforced by various hybrid configurations of reinforcement , tested up to failure under a cyclic loading in four points bending, to determine the best combination of the strengthening scheme.

1 INTRODUCTION

Nowadays, FRP composite materials have become an attractive solution for the repair and strengthening of structures, particularly concrete structures; this is due to the numerous advantages of these materials, namely their good behaviour towards corrosion, their lightness and their better strength.

However, the external strengthening of reinforced concrete beams using FRP was established as an efficient way to increase their strength, in both shear and in flexure, this strengthening method does have some inconveniences. As a consequence, when FRPs are used for flexural strengthening of beams reinforced with conventional steel, the reinforcement may yield before the FRP starts contributing to any supplementary strength capacity of the beam with at the end a brittle and a fragile failure. Consequently, it would be difficult to obtain a significant increase in the ductility or in the stiffness for the beam.

In seismic zones, the ductility of reinforced concrete elements is an important design criterion and, in this sense, a number of solutions have been put forward to improve such a structural quality, such as:

- Confinement concrete up-to the compression zone [Naaman A,1993] however, this method is only practicable for beams without slab floors.
- Using a hybrid FRP. [Grace Nabil and al 2003;D.Kachlakev and al 2000; Zhishen Wua 2006]

[Saadatmanesh and Ehsani 1991] have studied the strengthening of beams with strips in glass fibre reinforced plastics (GFRP); they have concluded that the bonding of GFRP strips reduces considerably the crack widths at all the levels of loading. They have also indicated that the use of GFRP strips reduces the ductility of beams.[Triantafillou 1998] showed that bonding FRP fabrics or sheets to the sides of beams improves their shear strength .recently[Guido Camata et al 2007] have studied experimentally and analytically the cases of CFRP and GFRP strengthening of beams; they have deduced that the contact surface of the strengthening material increases the ductility.

Use of hybrid FRP laminates, which consist of a combination of carbon and glass fibers fabrics, or a hybrid fabric HFRP, (Table1).

We are introduced in this study, a new Hybrid bidirectional fabric braided with carbon and glass fibres at 90°.

Different combinations of CFRP, GFRP and HFRP laminates (Fig.2) were attached to the beams to predict the best scheme of strengthening in the aim of increasing both their ultimate strength capacity and their ductility.

2 EXPERIMENTATION

The experimental work consisted of testing ten simply supported beams; all beams had the same dimensions and the same reinforcement in flexure and shear. Two 10 mm diameter steel bars were used for flexural reinforcement at the bottom and two 8 mm diameter were used the top. Steel stirrups of 6 mm diameters, spaced at 120 mm apart, were used for shear.

The beams had a rectangular cross section with 100 mm width,160 mm height and length of 1500 mm; with clear span of 1300 mm, Fig (1).

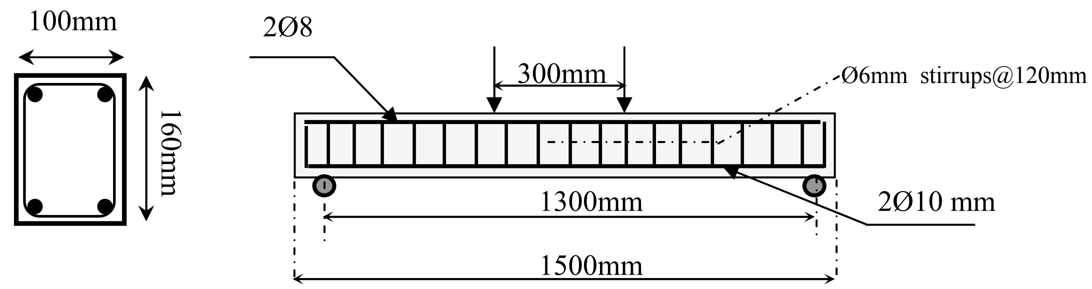

Fig.1- Details of test beams

The beams were abraded to remove the weak concrete material at the surface, cleaned with an air nozzle and finally wiped off to remove any dust or loose particles that might deter perfect bonding.

The beams were subjected to cyclic loading up to failure using a hydraulic machine of 250kN capacity. The four-point bending tests were carried out at displacement control using a constant displacement rate of 0.02 mm/s under the effect of two concentrated loads applied at 150 mm each from mid-span at the top of the specimens.

The deflection of the beam specimens is measured at mid-span with the help of a digital data recording camera and with displacement transducers (LVDT) placed respectively on the beam specimens and on the loading arm of the testing machine. The test beams were equipped with stain gauges for strain measurements in concrete and in the steel reinforcement imbedded inside.

The average concrete strength in compression was 38 Mpa; the yield strength of the steel bars used as tensile, shear and compressed reinforcement has been determined by standard tensile tests; the average value was 580 Mpa.

Properties of strengthening materials used in the experiments are given in table 1, not that the properties given in ‘b’ are composite properties and not properties of the HFRP fibber.

Table 1: Properties of Strengthening FRP Materials [a,b]

[a] SIKA Manufacturer Data						
Material	Modulus of Elasticity	Tensile Strength Mpa	Fibers Orientation	Thickness mm	Elongation at Failure	Surface mass g/m^2
CFRP Sika Wrap 230C	230 Gpa	3500	Unidirectional	0,13	1,5%	225
CFRP Sika Carbodur	165 Gpa	2800	Unidirectional	1,2	1,7%	--
GFRP Sika wrap 430G	76 Gpa	2200	Unidirectional	0,17	2,8%	430
Epoxy Sika 330	3,8 Gpa	30	__	1	0,9%	500g
[b] Laboratory test.						
Hybrid Laminate HFRP	27Gpa	216	Bi-directional	-	0,85%	-

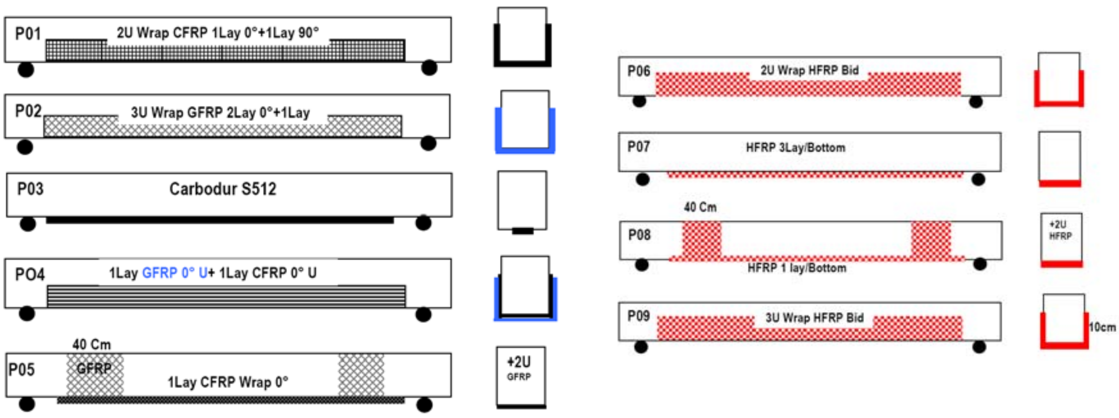

Fig.2- Strengthening schemes of tested beams.

3 TEST RESULTS AND DISCUSSION:

The tested specimens have exhibited different failure modes. These failure modes have been governed by the mechanical properties of the materials and by the strengthening configurations. For the purpose of this study, the ductility of a material could be defined as the ability of the material to undergo inelastic deformations without losing strength capacity. For comparison purposes, [Henrik Thomson et al. 2004] have used the definition of ductility based on energy. The energy ductility D_E is defined as the ratio between the energy of the system at failure E_u, and that at first steel yield E_y, that is :

$$\mu_E = E_u / E_y$$

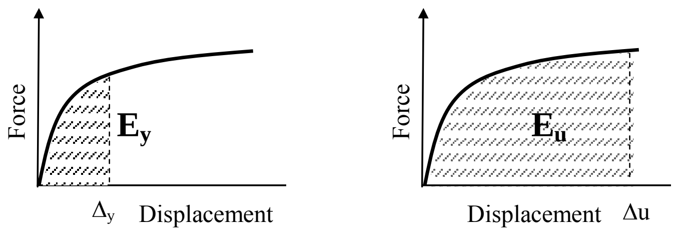

Fig .3. Definition of Ductility Index

For the purposes of this study, the first crack was defined as the point where the stiffness or beam modulus changed abruptly. Some specimens did not show an abrupt change but rather a gradual one. For these cases, an estimate of the point of transition was made. Failure was defined as the state where concrete reaches its ultimate strain in compression for the control specimen. For the strengthened specimens, however, failure was taken as that corresponding to a complete rupture of the composite material which coincides with an abrupt drop in the load carrying capacity of the beams.

The control specimen, noted Pc, had a yield load of 27,93 kN and a maximum load of 36,25kN,the beam failed by yielding of steel followed by compression failure of the concrete at midspan after exhibiting a considerable amount of ductility ,the ultimate deflection was 28,09 mm.

Beam P01 was strengthened with two layers of carbon fibres (CFRP) wrapping the beam in three faces (U shape) at the tension zone and placed perpendicularly to each other, one layer parallel to the longitudinal axis of the beam (at 0°) and the other perpendicular to the longitudinal axis of the beam (at 90°). The failure occurred by the rupture of the composite material in tension at a load of 78 KN while its ultimate deflection reached 19.3mm.

Beam P02 had a glass fibre (GFRP) strengthening material in three wrapping layers over three faces (U shape) at the tension zone; two layers placed parallel to the longitudinal axis of the beam (at 0°) and the third layer perpendicularly (at 90°). The failure load reached 79 kN, with a strength gain of 118% ; the deflection recorded at ultimate was 19mm. It should be noted that these two strengthening configurations have resulted in practically comparable results with no loss compared to the control specimen, (Fig.7).

Beam P03 (Fig.4) was strengthened in flexure with carbodur fibre laminates at the bottom face. The carbodur fibre plate bonded at the soffit has delayed considerably the crack formation in the beam and when formed, they were comparatively narrower with the control specimen. Shear cracking, however, was very wide and the carbodur fibre strengthening plate does not seem to have a beneficial effect on shear. Indeed the failure by shear was close to a support at an ultimate load of 69 KN (Fig.6), without the rupture of the fibre composite material. The failure was followed by a complete debonding of the carbodur plate glued on the soffit face of the beam and a delamination of the covering concrete after an inclined shear crack had run into it at one of its ends. This beam specimen was not ductile by comparison to the others and had brittle behaviour.

Beam P04 (Fig.5)had a hybrid strengthening configuration with combination of CFRP and GFRP fabric wrapped in U-shape over three faces in one layer each ,the layers were attached parallel to the beam axis at 0° ,the beam had reached a maximum load of 86,4kN representing a strength gain of 138%,and a deflection at failure of 23,95mm,noted for this beam ,the failure of this beam was ductile ,since the ductility index was 8,81, comparable to that of the control specimen, the failure was progressive which is attributed to use a hybrid combination of glass and carbon ,failure was progressive and the load dropped gradually with a distinguishable sound which is attributed to using the hybrid combination of GFRP and CFRP fabric.

Beam P05, had a hybrid strengthening a combination of longitudinal CFRP fabric for flexure attached on the bottom face with two ends GFRP anchorages of 300mm width each.

Flexure cracks appeared at the midspan of the beam; the beam failed brittle by the rupture of the composite and was exhibited less stiffness than the others beams of series A.; noted that the presence of the vertical layers of GFRP fabric only at the ends of the beam limited the propagation of crack to the unstrengthened area of the beam.

Beams P06, P07 and P08 ,Fig. 6, had a hybrid strengthening configuration, glass-carbon (HFRP); beams P07 and P08 did not give the results expected since all the tested specimens had fragile and brittle behaviour with the failure of the fibre composite material itself; This is explained by a configuration which is not in U shape. and the low modulus of HFRP.

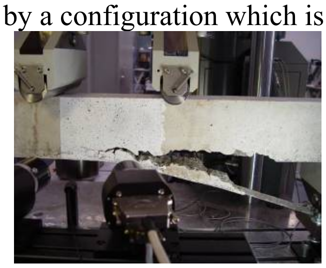

Fig.4 : Failure of Specimen P03

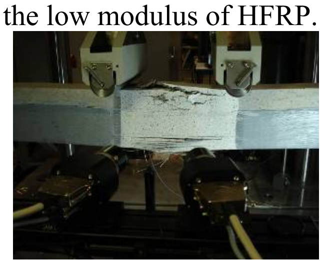

Fig.5 : Failure of Specimen P04

Beam P09, was strengthened with three layers of the hybrid fabric, glass-carbon HFRP, with U shape, in the same fibre fabric over the whole clear span. This strengthening configuration had resulted in a strength gain of 114%, The beam has failed by crushing of the concrete at the compression zone at an ultimate load of 76 kN, with a deflection of 16,86kN.

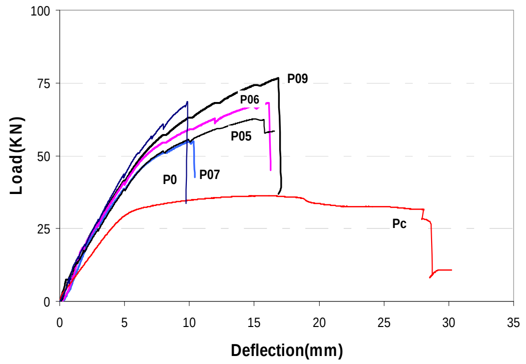

Fig .6 : Load-deflection curves for specimens (Pc, P03, P05, P06, P07,P08)

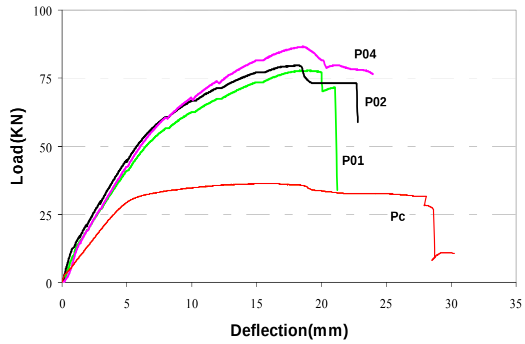

Fig.7 : Load-deflection curves for specimens (Pc,P01, P02,P04)

From the loading tests carried out on strengthened concrete beams, the following comments can be made on the structural benefits of this type of strengthening material:

1. At the initial loading stage, the strengthening material does not contribute to any supplementary stiffness in comparison to the control beam specimen. However, the initial stiffness of the beam is conserved when the fibre fabrics strengthening material is used whereas that of the control specimen decreases rapidly as soon as the concrete cracks at the tension face down the bottom. It should be noted that all the strengthening configurations adopted in the tests have increased the stiffness by an average of 20 %.

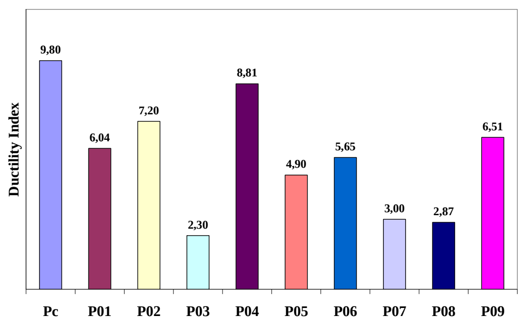

Fig.8-Ductility Index in term of Energy

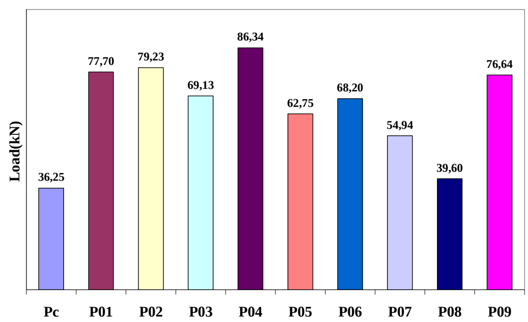

Fig.9-Load at Failure

2. For the yielding of the beams, the control specimen started its plastic deformation earlier. Beams P01, P03 and P04, strengthened with different confirmations of fibre fabric, started yielding at loads 25 % higher on average.
3. As for the ultimate loads of the tested specimens, three comments can be made:

- The highest load was obtained for beam P04 with a hybrid glass/carbon fibres strengthening configuration, giving a strength gain of 138%, followed respectively by beam P03, beam P09, beam P01 and finally beam P02.
- The deflection of beams strengthened with hybrid fabrics (HFRP) was systematically less than the control specimen.

4. In post failure, the strengthened beams globally behaved in a brittle manner, except beams P04 and P02 which did have a ductile behaviour. After failure, the load displacement curves became similar to that of the control specimen.

4 CONCLUSIONS

Based on the present experimental work, the following conclusions can be made:

1. The combination of the strengthening laminates GFRP and CFRP noticeably increases the ultimate load capacity and stiffness of the beams; and it is an effective method to enhance theirs ductility.
2. In beam specimens having hybrid strengthening glass/carbon, the displacement at failure is similar to that of the control specimen. Following the fact that an increase in defection is the result of a great capacity of energy absorption by the strengthened beams, this expresses an improvement or at least the maintaining of the existing ductility.
3. The use of U-shaped strengthening configurations allows for an increase in the contact area of the fabric and, hence, its ductility. It prevents any premature longitudinal bond failure.
4. The use of vertical sheets is essential so that the growth of diagonal cracks will be limited.

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